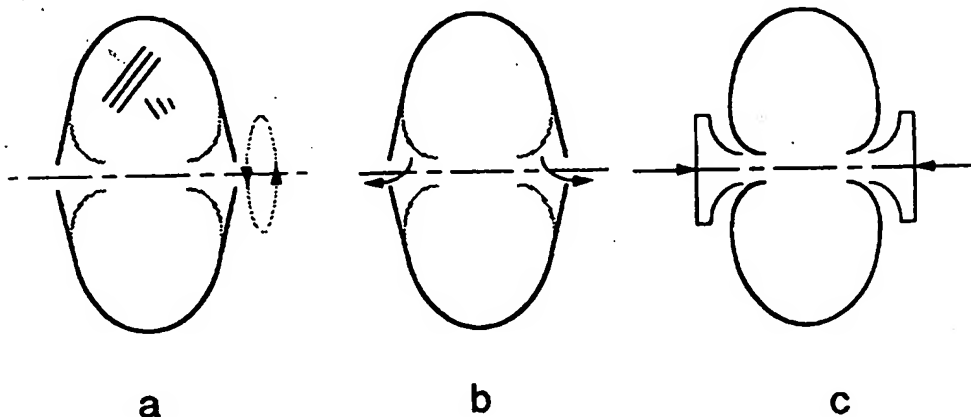




## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification <sup>6</sup> : <b>F17C 1/06, B65D 88/02, B60K 15/03, 15/073</b>		A1	(11) International Publication Number: <b>WO 97/17570</b>
			(43) International Publication Date: 15 May 1997 (15.05.97)
(21) International Application Number: PCT/NL96/00437		(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TR, TT, UA, UG, US, UZ, VN, ARIPO patent (KE, LS, MW, SD, SZ, UG), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).	
(22) International Filing Date: 8 November 1996 (08.11.96)		Published With international search report.	
(30) Priority Data: 95203044.3 8 November 1995 (08.11.95) EP			
(34) Countries for which the regional or international application was filed: NL et al.			
(71) Applicant (for all designated States except US): TECHNISCHE UNIVERSITEIT DELFT [NL/NL]; Julianalaan 136, NL-2628 BL Delft (NL).			
(72) Inventors; and			
(75) Inventors/Applicants (for US only): BEUKERS, Adriaan [NL/NL]; Alberdinck Thijmalaan 17, NL-2106 EG Heemstede (NL). DE JONG, Theo [NL/NL]; Chopinplein 16, NL-2421 TT Nieuwkoop (NL).			
(74) Agent: SMULDERS, Th., A., H., J.; Verenigde Octrooibureaux, Nieuwe Parklaan 97, NL-2587 BN The Hague (NL).			

(54) Title: PRESSURE-RESISTANT VESSEL



## (57) Abstract

The invention is directed to a wheel-shaped pressure-resistant vessel for gaseous, liquid or liquefied material having a substantially rigid shape, said vessel comprising a substantially continuous shell of a fiber-reinforced resin having a central opening, an inner lining and an axial member, said substantially continuous shell having a substantial mechanical equilibrium shape, whereby the axial member is present in the said central opening of the shell.

**FOR THE PURPOSES OF INFORMATION ONLY**

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AM	Armenia	GB	United Kingdom	MW	Malawi
AT	Austria	GE	Georgia	MX	Mexico
AU	Australia	GN	Guinea	NE	Niger
BB	Barbados	GR	Greece	NL	Netherlands
BE	Belgium	HU	Hungary	NO	Norway
BF	Burkina Faso	IE	Ireland	NZ	New Zealand
BG	Bulgaria	IT	Italy	PL	Poland
BJ	Benin	JP	Japan	PT	Portugal
BR	Brazil	KE	Kenya	RO	Romania
BY	Belarus	KG	Kyrgyzstan	RU	Russian Federation
CA	Canada	KP	Democratic People's Republic of Korea	SD	Sudan
CF	Central African Republic	KR	Republic of Korea	SE	Sweden
CG	Congo	KZ	Kazakhstan	SG	Singapore
CH	Switzerland	LJ	Liechtenstein	SI	Slovenia
CI	Côte d'Ivoire	LK	Sri Lanka	SK	Slovakia
CM	Cameroon	LR	Liberia	SN	Senegal
CN	China	LT	Lithuania	SZ	Swaziland
CS	Czechoslovakia	LU	Luxembourg	TD	Chad
CZ	Czech Republic	LV	Latvia	TG	Togo
DE	Germany	MC	Monaco	TJ	Tajikistan
DK	Denmark	MD	Republic of Moldova	TT	Trinidad and Tobago
EE	Estonia	MG	Madagascar	UA	Ukraine
ES	Spain	ML	Mali	UG	Uganda
FI	Finland	MN	Mongolia	US	United States of America
FR	France	MR	Mauritania	UZ	Uzbekistan
GA	Gabon			VN	Viet Nam

Title: Pressure resistant vessel

The present invention is directed to a pressure vessel for gaseous, liquefied or liquid materials and the like.

Pressure resistant vessels have been in use for numerous applications, one of them being the use as LPG-container for automotive purposes. LPG being an interesting fuel for automotive purposes, i.a. due to the low price and low emission of environmentally harmful substances, the use thereof has increased substantially over the last decades. However, LPG is a material that has been liquified through pressurisation, with the consequence that the requirements for safety are very high. In view of their relatively low costs, generally steel pressure tanks are used for storage of LPG, said pressure tanks generally being substantially cylindrical and having torispherical domes.

A distinct disadvantage of these LPG containers is their weight and the amount of space they require in a car. In the smaller (compact) cars this weight and especially the amount of space required makes the use of LPG as fuel rather unattractive.

It is an object of the invention to provide a pressure vessel having a relatively low weight, and a shape which makes it better suitable for automotive applications. An other object is to provide a pressure vessel which may be used by a person carrying the vessel, for example on the back.

The invention is based on the development of a wheel shaped vessel, which vessel may have the size of a spare car wheel and which will fit in the area provided for said spare wheel.

The invention is accordingly directed to a wheel shaped pressure resistant vessel for gaseous, liquid or liquefied material having a substantially rigid shape, said vessel comprising a substantially continuous shell of a fiber

reinforced resin having a central opening, an inner lining and an axial member, said substantially continuous shell having a substantial mechanical equilibrium shape, whereby the axial member is present in the said central opening of the shell.

5 A preferred embodiment of the invention provides a wheel shaped pressure resistant vessel, comprising a substantially continuous shell of a fiber reinforced elastomeric resin having a central opening, a gas tight, substantially rigid inner lining and an axial member, said substantially  
10 continuous shell having a substantial mechanical equilibrium shape, whereby the axial member is present in the said central opening of the shell and is attached to the rims of the central opening, thereby closing the said central opening.

The shell is comprised of a fiber reinforced resin body.  
15 The fibers have been wound along substantially geodetical lines, and the shape of the vessel is designed so that the load is substantially equal everywhere in the fibers (more or less isotensoid). Preferably a combination of relatively stiff fiber re-inforcement and flexible matrix material is chosen,  
20 resulting therein, that the design, production and use of the vessel is very tolerant for deviations and stress-concentrations. Deviations of geodetics and/or continuity becomes possible to a certain extent, provided the structural integrity is maintained.

25 The so-called "netting" theory has been used for this design. This theory assumes that in case of the use of stiff fibers in a non-rigid (such as elastomeric) matrix, the influence of the matrix may be discounted for calculating the forces in a system of fibers of a wound construction. This  
30 theory is valid when the stiffness of the matrix is negligibly small compared to the stiffness of the fibers. A theoretical report on the development of pressure bodies using the netting theory can be found in the report of the Technical University of Delft, The Netherlands, report VTH-166, which is  
35 incorporated herein by way of reference.

Winding the substantially continuous fiber reinforcement along a substantially rotation symmetrical body results then

in an equilibrium shape that is non-spherical, preferably approximately elliptical, and determined by the form parameter  $q$  as defined in the said report. In view of the applicability of analytical methods, such as the netting theory to the present invention, which is justified by the difference in stiffness between the fibers and the matrix, the use of continuous fibers for the winding of the body will lead to the situation where the tension in all the fibers is substantially equal throughout the body (isotenoid).

The shape and size of the vessel is determined by the following differential equation (See also figure 1)

$$\frac{dX}{dY} = \pm \frac{\sqrt{a^2(Y^2-1) - (Y^3 + kY)^2}}{Y^3 + kY}$$

wherein

$$X = \frac{x}{y_0}, \quad Y = \frac{y}{y_0}, \quad a = \frac{nF}{\pi p y_0^2}, \quad k = \frac{K}{\pi p y_0^2}$$

$F$  Tension force in the fibres

$K$  axial load on the poles of the vessel

$X, Y$  dimensionless co-ordinate axis

$x, y$  co-ordinate axis

$a$  constant; describes relation between internal pressure and number of fibres

$k$  constant; describes relation between internal pressure and polar load

$n$  number of yarns in cross-section

$p$  internal pressure

$y_0$  polar opening radius

An inflatable body of a somewhat comparable shape has been disclosed in EP-A 626,338, the contents of which is incorporated herein by reference. The essential differences between this known body and the present invention are, among others, the requirement of a rigid shape, preferably provided by the lining and the axial member.

The vessel of the present invention may have different constructions, depending on the materials used and the actual requirements on the size, shape and strength.

An essential requirement is that the vessel is rigid. This means, that either the shell is rigid, or that the inner lining is rigid. In this context the term rigid is understood to mean, that without internal pressure, the shape of the vessel is substantially maintained.

The shell, prepared from fiber reinforced resin, can either be rigid or flexible. In a preferred embodiment the shell is prepared from an elastomeric resin, such as a vulcanised or thermoplastic rubber.

The inner lining may also be rigid or thermoplastic. In case the shell is flexible it is essential that the lining is rigid. Otherwise the selection may be made based on criteria of construction and gaspermeability.

The axial member may have two functions in the pressure vessel according to the invention. In the first place this member may provide the necessary means for attachment of all accessories or appliances that are required for the actual use as a pressure vessel. It is for example possible to accommodate all said means inside the axial member, or on top thereof. In the second place, and this is much more important, the axial member provides the necessary axial reinforcement of the vessel, by providing a link between the two surfaces of the shell, thus closing the vessel, and pulling the two surfaces together. This latter effect is very important in terms of the shape of the vessel. Without the link the shape would become too much of a balloon to be suitable for use.

This axial member may be provided by a separate element, such as disclosed in figures 2<sup>a</sup> and 4, or by winding the fiber reinforcement through the opening in the vessel.

According to a preferred embodiment the axial member does not extend beyond the planes defining the outmost surface of the shell of the pressure vessel. Thereby the rim of the central opening in the shell is pulled inward, thus creating an actual wheel like shape.

The vessel body has a geometrically continuous shape and substantially no stress concentrations occur, with the exception in the area where the axial reinforcement member holds the two surfaces together. The shape of the body contains substantially no discontinuities in the mathematical sense, with the exceptions discussed above.

To enable the vessel to hold gases or liquids, an gas-tight inner lining is present. This lining is preferably substantially rigid, thus providing the required shape to the pressure vessel. The material of the inner lining will be selected in relation to the intended application. Of course the material has to be gastight at the thickness used, which means that the amount of gas passing through it should not exceed the criteria of the applicable laws and regulations. Suitable values thereof are less than 10 ml/h, independent of surface area.

Furthermore the material must be resistant to chemical influences of the gas or liquid. Finally it must be able to withstand the external forces, that could be exerted on the vessel, such as crash-loads, penetration, indentation and the like. Suitable materials for the inner lining are i.a. the various non-elastomeric ethylene and propylene polymers, PVC and copolymers, as well as metals, such as steel or aluminium.

To protect the vessel against foreign objects, damage, wear, environmental influences, chemicals, such as oils, acids, lye, fats and the like, a protective outer lining may be used. Preferably this outer lining is able to withstand mechanical and thermal abuse without early collapse.

The pressure vessel according to the invention may be used as an LPG container for automotive use, as discussed hereinabove, but also for other applications wherein pressure vessels can be useful. Examples thereof are lightweight, crash resistant pressure vessels, for example for holding hazardous gases or liquids under high pressure, such as gaseous, liquefied or liquid propellants in the aerospace industry. Other applications can be the storage of oxygen or air for rescue workers, fuel for cooking or other equipment, cryogenic

storage (provided a suitable isolation is present, for example in the form of a foam between two walls in a double walled vessel), fire extinguishing liquids or gases, and the like.

The vessel can be fire proof by the choice of the materials of construction thereof, or by the use of suitable fire proofing additives or barriers therein.

The pressure that the vessel can withstand depends on the construction thereof, and more in particular on the fiber density in the shell. Generally the vessel can withstand pressures from little above atmospheric to more than 100 bar, for example up to 400 bar.

The fabrication of the fiber reinforced resin body can take place in various ways. A suitable method is winding a pre-impregnated fiber around the rotation symmetric core (for example the rigid inner lining), optionally followed by further impregnation of the final fiber reinforcement with the resin and solidification and/or vulcanization. However it is also possible to apply a resin matrix to the substantially rotation symmetric core prior to the winding of the fibers and/or after the winding of the fibers. After the fiber reinforcement has been wound around the core, the core is removed. This can be done by using a core that collapses in parts, by a temporary core composed of loosely bound solids, a core of hardened glass, which may be broken and removed after production, or an inflatable core.

In order to provide the required shape in the area of the inner rim of the shell, the shape of the lining preferably deviates somewhat from the theoretical equilibrium shape. As has been shown in figure 3 the surface extends somewhat outwardly, thus enabling the attachment of the axial member, after the extending part has been inverted inside.

After the fiber reinforcement body has been wound, woven or braided it can be incorporated in a resin matrix. It is also possible to wind resin-impregnated fibers, which results in the forming of the resin matrix. In a preferred embodiment the shell is produced by first applying a layer of resin material on the body, preferably an elastomer, subsequently



winding one or more layers of fibers (strands) around this body, preferably two layers, and finally again applying a final layer, a resistance layer, over the final layer of fibers.

5       The matrix can then be solidified, for example by vulcanisation.

      The fiber reinforcement can be constructed from various materials, generally comprising natural or synthetic organic or inorganic fibers, although the well-known aramid fibers, 10 such as Kevlar (TM) and Twaron (TM) are a suitable choice. Those fibers provide sufficient tensile stiffness in combination with strength. Other suitable fibers are all those fibers with a high tensile strength and/or stiffness, like sisal, carbon fibers, E-, R- and S-glass fibers, and those 15 polymeric fibers which are suitable in the environments where the vessels are used, such as the high molecular weight polyethylene fibers, polyester fibers and other fibers from high quality plastics (engineering plastics).

      The matrix resin material of the shell may be 20 elastomeric, or rigid. Preferably the shell is prepared from a fiber reinforced resin selected from the group of elastomeric, thermoplastic elastomeric, thermosetting and thermoplastic, non-elastomeric resins. As the elastomer matrix any suitable elastomer can be used, although it is preferred that a high 25 quality elastomer having a good resistance against environmental degradation, such as ozone resistance, is used. Suitable elastomers are for example the isoprene, polyurethane, styrene-butadiene, butadiene-nitrile, EP(D)M, polybutadiene and silicone elastomers, which are optionally 30 vulcanised after the body has been shaped. The most preferred elastomer, especially for use as an LPG container is chloroprene rubber.

      The invention is elucidated on the basis of the following figures, without being restricted thereto.

35       In figure 1 the principle equation for designing the vessel, together with a schematic drawing showing some of the variables is given. In figures 2<sup>a-c</sup> the principle of preparing

the shell of the vessel is shown. Figure 3 gives the X-Y relation in the wound (equilibrium) shape and the final shape, after insertion of the axial member.

5 In figure 4 the construction of part of the assembled vessel with separate axial member is given. The end plate 1, provided with valve 2, is attached by means not shown to axial reinforcement member 3 and to end ring 4. Thereby a  
10 cylindrical enclosure is formed inside the central part of the shell, the rims of which are held in place between the end plate 1 and end ring 4.

CLAIMS

1. Wheel shaped pressure resistant vessel for gaseous, liquid or liquefied material having a substantially rigid shape, said vessel comprising a substantially continuous shell of a fiber reinforced resin having a central opening, an inner lining and an axial member, said substantially continuous  
5 shell having a substantial mechanical equilibrium shape, whereby the axial member is present in the said central opening of the shell.
2. Vessel according to claim 1, comprising a  
10 substantially continuous shell of a flexible fiber reinforced elastomeric resin and a gas tight, substantially rigid inner lining.
3. Vessel according to claim 1 or 2, whereby the axial reinforcement member is present in the said central opening of  
15 the shell and is attached to the rims of the central opening, thereby closing the said central opening.
4. Vessel according to claim 1-3, wherein the axial member is attached to the shell in such way that the surfaces of the shell are pulled towards each other.
- 20 5. Vessel according to claim 1 -4, wherein the axial member comprises an inner member and two end plates, said end plates fixing the shell to the inner member.
6. Vessel according to claim 1-5, wherein the said axial member is provided with means for filling the vessel  
25 with the pressurised material, means for removing the said material from the vessel and/or means for determining the pressure and/or filling degree of the vessel.
7. Vessel according to claim 1-6. wherein the shell is prepared from a fiber reinforced resin selected from the group  
30 of elastomeric, thermoplastic elastomeric, thermosetting and

thermoplastic, non-elastomeric resins, preferably chloroprene resin.

8. Vessel according to claim 1-7, wherein the fiber reinforcement of the shell is selected from the group of organic and inorganic fibers, more in particular polyamide fibers, carbon fibers, polyolefinic fibers, preferably aramide.

9. Vessel according to claim 1-8, wherein the ratio of the diameter of the central opening to the outer diameter of the vessel ranges from 0.1 to 1.

10. Use of a vessel according to claim 1-9, as an LPG-container for automotive purposes.

1/2

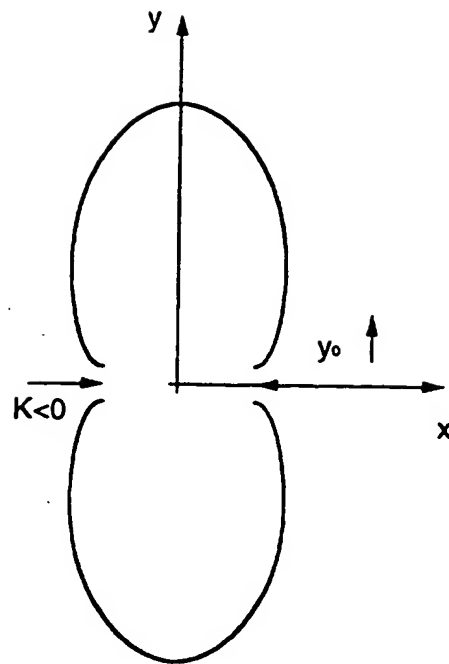


Fig. 1

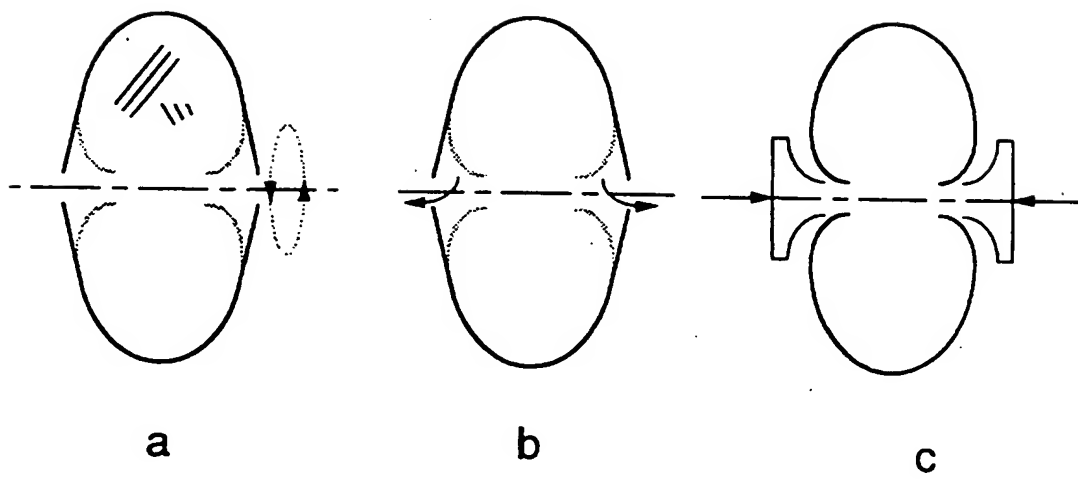


Fig. 2

2/2

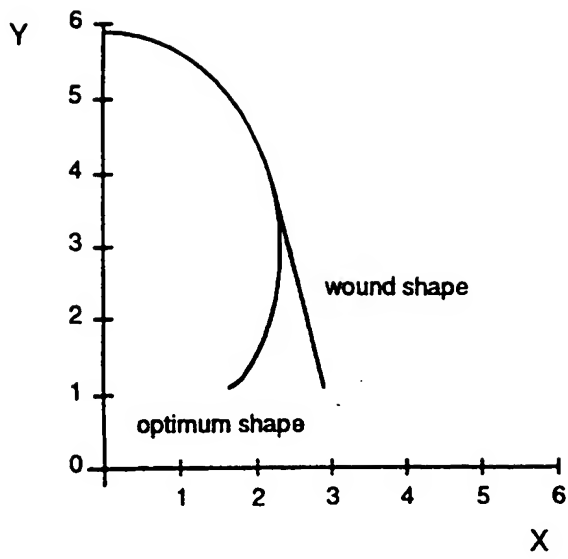


Fig. 3

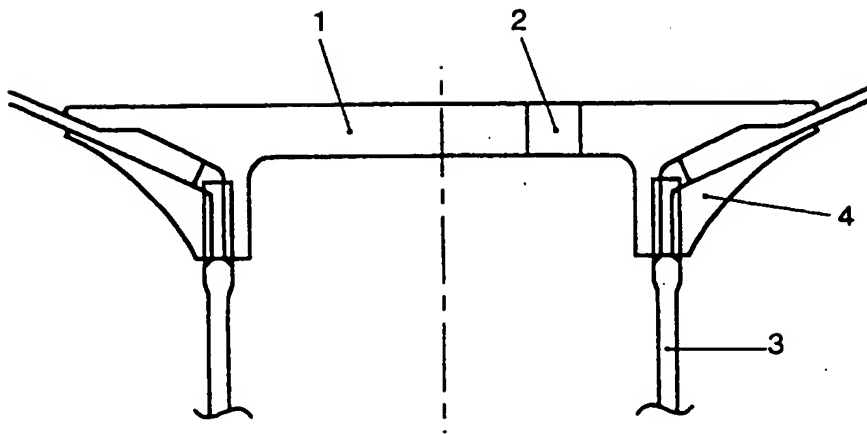


Fig. 4

# INTERNATIONAL SEARCH REPORT

National Application No  
PCT/NL 96/00437

**A. CLASSIFICATION OF SUBJECT MATTER**  
IPC 6 F17C1/06 B65D88/02 B60K15/03 B60K15/073

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)  
IPC 6 F17C B65D B60K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	GB,A,117 343 (JAGGER) 8 August 1918 ---	
A	GB,A,1 061 596 (TEMPLETON) 15 March 1967 -----	

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

\* Special categories of cited documents:

- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier document but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed

- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- "A" document member of the same patent family

Date of the actual completion of the international search

7 January 1997

Date of mailing of the international search report

15.01.97

Name and mailing address of the ISA  
European Patent Office, P.B. 5818 Patentaan 2  
NL - 2280 HV Rijswijk  
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,  
Fax: (+31-70) 340-3016

Authorized officer

Meertens, J

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/NL 96/00437

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
GB-A-117343		NONE	
GB-A-1061596		NONE	